# DEGRADATION MODELLING ON TEMPERATURE UPON BURST CAPACITY OF COMPOSITE REPAIRED PIPELINE

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## STUDENT’S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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## ABSTRAK

Saluran paip adalah cara yang paling selamat, cekap, dan ekonomi untuk pengangkutan minyak dan gas untuk jarak yang jauh. Ia tertakluk kepada kemerosotan dan kerosakan, yang boleh mengurangkan kekuatan dan integriti struktur. Komposit polimer diperkuat gentian *(FRP)* digunakan untuk membaiki paip keluli yang rosak dan ia telah terbukti berkesan kerana ia dapat memulihkan kapasiti muatan paip keluli. Walau bagaimanapun, *FRP* komposit terdedah kepada beberapa faktor persekitaran yang mengakibatkan degradasi seperti suhu, kelembapan, radiasi ultraungu, kitaran haba, dan keletihan mekanikal. Degradasi komposit *FRP* dijangka mengurangkan kapasiti galas beban paip diperbaiki oleh komposit. Oleh itu, tujuan kajian ini adalah untuk mengkaji kesan suhu terhadap degradasi E-kaca / Vinylester ke atas paip diperbaiki komposit melalui analisis unsur terhingga *(FEA)*. Komposit E-kaca / Vinylester tertakluk kepada suhu yang berbeza iaitu 23 ° C, 60 ° C, dan 95 ° C pada 0-hari, 360-hari, 1080-hari, dan 1440-hari. Sepuluh model unsur terhingga telah dihasilkan untuk mensimulasikan kesan degradasi komposit terhadap tekanan letus saluran paip diperbaiki komposit. Keputusan menunjukkan bahawa tekanan letus paip keluli diperbaiki komposit menurun dengan ketara sebanyak 10.09% dan 11.62% dalam masa 360 hari pada 60°C dan 95°C. Sementara itu, pengurangan tekanan letus sebanyak 7.29% diperhatikan pada 1080-hari apabila paip diperbaiki komposit adalah tertakluk kepada 23°C. Kesimpulannya, degradasi komposit E-kaca / Vinylester dari masa ke masa mempunyai kesan ke atas kapasiti galas beban paip keluli diperbaiki komposit. Pengurangan kekuatan tegangan dalam komposit telah mengurangkan kapasiti letus saluran paip diperbaiki komposit. Penemuan ini boleh menjadi sangat berguna dalam memahami ketahanan jangka panjang paip keluli diperbaiki komposit.

## ABSTRACT


Pipelines are the safest, efficient, and economic way for oil and gas transportation over a long distance. It is subjected to deterioration and damage, which can reduce their strength and structural integrity. Fiber-Reinforced Polymer (FRP) composites are used to repair defective steel pipes and it has been proven effective as it restored the loading capacity of steel pipe. However, FRP composites are susceptible to be degraded by several environmental factors such as temperature, moisture, ultraviolet radiation, thermal cycling, and mechanical fatigue. Degradation of FRP composites are expected to decrease the load bearing capacity of composite repaired steel pipe. Therefore, the purpose of this research is to study the effect of temperature towards the degradation of E-glass/Vinylester on composite repaired pipeline through finite element analysis (FEA). The E-glass/Vinylester composites were subjected to different temperatures which are 23°C, 60°C, and 95°C at 0-day, 360-days, 1080-days, and 1440-days. Ten finite element (FE) models were developed to simulate the effect of composite degradation upon the burst pressure of composite repaired pipeline. The results show that burst pressure of composite repaired steel pipe dropped significantly by 10.09% and 11.62% within 360-days at 60°C and 95°C, respectively. Meanwhile, a reduction of burst pressure by 7.29% at 1080-days was observed when the composite repaired pipe was subjected to 23°C. As a conclusion, degradation of E-glass/Vinylester composites over time has the effect on load bearing capacity of composite repaired steel pipe. Reduction of tensile strength in composite had reduced the burst capacity of composite repaired pipeline. This finding can be very useful in understanding the long-term durability of composite repaired steel pipe.

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# LIST OF SYMBOLS

| | |
|---|---|
| E1 | Hoop Tensile Modulus |
| E2 | Axial Tensile Modulus |
| E3 | Radial Tensile Modulus |
| G | Shear Modulus |
| $T_g$ | Glass Transition Temperature |
| v | Poison Ratio |
| $\sigma_a$ | Axial Tensile Stress |
| $\sigma_h$ | Hoop Tensile Stress |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| CFEP | Carbon Fiber-Epoxy Polymer |
| CFRP | Carbon Fiber Reinforced Polymer |
| CFPP | Carbon Fiber-Polyester Polymer |
| FEA | Finite Element Analysis |
| FRP | Fiber Reinforced Polymer |
| GFEP | Glass Fiber-Epoxy Polymer |
| GFRP | Glass Fiber Reinforced Polymer |
| GFPP | Glass Fiber-Polyester Polymer |
| MCU | Moisture Cured Urethane |
| PGU | Peninsular Gas Utilisation |
| RMB | Renminbi |
| R&D | Research & Development |
| SSGP | Sabah-Sarawak Gas Pipeline |
| UV | Ultraviolet |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

Nowadays, pipelines are considered as the safest, efficiency and economic way to transport natural gas, petroleum, refined products in a large quantity over a long distance. Pipelines are subjected to internal and external damage caused by several factors such as material and construction defects, natural forces, corrosion, and third-party damage (Yusof *et al.*, 2014; Lim *et al.*, 2015). Steel pipeline is susceptible to corrode with the presence of water. Corrosion rate will be faster under harsh environment compared to the common environment. Damaged or corroded pipelines can degrade its mechanical properties and reduce its strength throughout service life (Nakamura *et al.*, 2006; Ossai *et al.*, 2015). Eventually, these pipelines are potentially subjected to failure such as leaking and explosion. Failure of pipelines can cause significant negative impact such as loss of live, destruction of private and public property, and serious environmental damage.

In June 10, 2014 an explosion of Sabah-Sarawak Gas Pipeline (SSGP) in Lawas, Sarawak was reported where the main reason of explosion is believed due to leaking of pipeline (Ismail, 2014). This explosion results a temporary shutdown of pipeline operation that is worth with RM 4 billion that owned by national oil giant, Petronas (Then, 2014). Another explosion of underground gas pipeline in Kaohsiung, Taiwan happened on July 31,2014 has caused fatality of 32 people and almost 321 people were injured due to leaking of propylene gas (Chen *et al.*, 2016). Incident on November 22, 2013 occurred at Donghuang, China where direct economic lost is approximately 751,720,000 RMB, 136 people are injured and 62 people are died due to pipeline leakage and explosion (Gong and Li, 2018). Failure of pipeline will only give negative impacts to public and environment. Therefore, maintenance and repairing for pipeline system are necessary to prevent failure.

For years, a range of technique are available for rehabilitation of damaged pipeline on offshore or onshore. The most common method for repairing damaged pipeline is to remove the defective segment and replace it with new pipeline. Shutdown or isolation and depressurization are necessary for the defective segment of pipeline in this repair method (Jakso *et al.*, 2006). A temporary shutdown will affect the operation and cause significant loss for company. Other than this method, installation of full-encirclement steel sleeves is another widely used rehabilitation method where steel sleeves are used to cover the defective segment. This method is generally suitable for straight pipeline and it is difficult to be applied on bended pipeline. Both methods which involves welding or clamping of pipeline is hard to be done in limited workplace such as in underground environment (Lim *et al.*, 2015).

Recently, there is a trend of the application of Fiber Reinforced Polymer (FRP) composite as rehabilitation technique in different fields of engineering such as aircraft, structural buildings, aerospace and etc. This FRP composite application is used in pipeline repair method and it has been proven effective for repairing defective pipeline and other steel structures (Duell *et al.*, 2008; Chan *et al.*, 2015). However, FRP composite still have several issues regarding to the behaviour and performance of composite repair system are not fully understood. These issues consist of complexity of surface preparation, delamination and de-bonding between steel pipe and composite, performance and contribution of the infill material, load transfer mechanisms, effect of defect geometries, and conservativeness in existing design codes (Lim, 2017). Thus, pipeline rehabilitation techniques and repair method always are the concern for researchers to study in order to have a better understanding on the behaviour of composite repair system, and subsequently improve its efficiency.

## 1.2 Research Problem

Fiber Reinforced Polymer (FRP) composite materials in pipeline rehabilitation consist of three parts which are FRP composite wrap, infill material, and adhesive. FRP composite wrap provides additional strength to defective pipeline and it acts as a protection layer to putty as well. The role of infill material is to fill the damaged part of pipeline and give a smooth surface for composite layer while adhesive is used to bond the composite layer with the infill material and damaged pipeline. Combination of those materials has been proven effective for pipeline repair system (Duell *et al.*, 2008; Chan *et al.*, 2015).

Fiber Reinforced Polymer (FRP) is a composite made of polymer matrix reinforced with fibers. Glass, carbon or aramid are typically fiber where they provide strength and stiffness to composite. Polymer matrix generally are thermoplastic or thermosetting resin such as epoxy, vinyl ester or polyester where it has the function of transfer load between fibers and protect fibers from environment (Liao *et al.*, 1998). FRP composite has unique properties such as high specified stiffness, high strength, high resistance against corrosion, high fatigue endurance limit, and lightweight (Liao *et al.*, 1998; Farooq, 2009; Hagihara *et al.*, 2018; Vieira *et al.*, 2018).

However, the mechanical properties of FRP composite are significantly degraded over time under various factors such as temperature, ultraviolet (UV) light, moisture content, and oxygen (Jawaid *et al.*, 2016). Degradation of FRP composite layer will potentially results a reduction in strength and durability of a composite repaired pipeline. Reduction in strength and durability of FRP composite increase possibility of pipeline failure prior to its design life. The degradation rate is different under various factors. Therefore, this research aims to study the effect of temperature towards the degradation of composite repaired pipeline.

## 1.3 Objectives

The main concern of this research is to study the effect of temperature towards the degradation of composite repaired pipeline through finite element analysis (FEA). The objectives of this study are as follows:

1. To study the strength degradation of FRP composite subjected to different temperatures.
2. To simulate the effect composite degradation upon the burst pressure of composite repaired pipeline.

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